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Computational and Information Sciences Directorate

Abstract

Modifications were made to the Combined Obscuration Model for Battlefield Induced Contaminants (COMBIC) code to obtain aerosol cloud-density values for multiple obscurant types. The main purpose of COMBIC has traditionally been to obtain the transmittance or optical depth for one or more lines of sight (LOSs). If one specifies optical depth, uses consistent units, and ensures that the product of mass extinction coefficient and optical path length is unity, output values will be numerically equal to the cloud density (g/m^3). This report provides information on the required input values, the modifications made to COMBIC, and the resulting output obtained when one or more sources comprising various obscurant types are provided as input. Examples are included that show various cases containing sources with one or more obscurant types as input. The density output files and the resulting visualized clouds are also given in this report. Specific recommendations for the appropriate input values required to produce valid cloud-density grids are indicated.

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1. Introduction

The Combined Obscuration Model for Battlefield Induced Contaminants (COMBIC) [1] has been used primarily by researchers to determine aerosol cloud sizes and positions and the reduction in the transmittance of electromagnetic energy for signals passing through these clouds. COMBIC data structures are optimized for calculating path integrals rather than providing cloud descriptions. The standard version of the COMBIC software allows the user to specify the location of one or more observers and targets to determine the transmittance along observer-to-target lines of sight (LOSs). It first computes time-dependent cloud skeletons and optical property descriptions for aerosols, which include explosions, munitions, dust, debris, and smoke. The scenarios for which COMBIC has been designed may be large, in that tens to hundreds of different obscuration sources and observer-to-target LOSs are considered simultaneously.

A particular feature of COMBIC is its ability to calculate either transmittance or optical depth. When the user selects the optical depth option, the process for obtaining density values is fairly straightforward. If one uses the appropriate units for relevant variables (mass extinction coefficient and optical path length) and the product of mass extinction coefficient and optical path length has the value of unity, then the optical depth is equal in magnitude to the aerosol cloud density. Hence, one can select appropriate input values to determine the density at desired locations and times.

Recently, we modified COMBIC to develop three-dimensional density fields in which aerosol cloud densities are printed at specified locations and time values. We did this because of a need to have smoke cloud densities processed as part of the Weather and Atmospheric Visualization Effects for Simulation (WAVES) package [2]. This package, which handles multiple clouds, predicts illumination and radiance information for a three-dimensional variable atmosphere. The modifications described in this report will help in allowing one to consider spatial and temporal variability of multiple smoke clouds. Also, the structure of these smoke clouds can be compared to the coarser structure of the clouds currently exhibited in WAVES. Appropriate header information that describes the relevant output, along with its size, is also included with the density output. In most of the work to date, we have been using three-dimensional grids on the order of magnitude of 0.1 to 0.5 km in each direction.

2. Theory and Methods

Transmittance is the quantity representing the fraction of electromagnetic energy that remains in the beam after passing along the optical path. In COMBIC, transmittance is calculated from the "Beer-Lambert" law,

$$T = e^{-\alpha CL} , \tag{1}$$

where α is the mass extinction coefficient and CL is the integral of the aerosol concentration (C) over the optical path length (L). The product αCL is dimensionless and is referred to as the optical depth. If the product of the mass extinction coefficient, α, and the optical path length, L, is unity, it is evident that the optical depth and the concentration (or density) are equal in magnitude. The units typically used are as follows: α, m^2/g; C, g/m^3; and L, m.

This modified version of COMBIC uses this feature to determine density values for each individual volumetric cell at each point in time. The modifications to the coding were primarily made in subroutines CNTUR and BTRANS. Originally, CNTUR was used to produce a printer plot file, which was a gray-scale plot of transmission or optical depth. Modifications were made to obtain the actual aerosol cloud-density values that were printed to the density file named in standard input. Prior to printing the density data, we printed several header values to ensure compatibility with the Vis5D software [3] used to visualize the density data.

COMBIC allows the computations to be performed in two phases. The first phase produces a cloud history file that contains the data for each cloud and includes all meteorological influences except wind direction. Each obscurant type is indicated on a separate MUNT card within phase I. In the second phase, COMBIC builds a user-defined scenario of smoke and dust sources. The path-integrated concentration is determined for each observer-target pair and the transmittance is then calculated at each of seven wavelength bands (ranging from visible to far IR wavelengths) in the original version. In determining the printer plot, one needs to note that there would normally be only a single SLOC card as part of the phase II input that would indicate which obscurant type is to be produced. Changes were made to the COMBIC code, however, that made the inclusion of more than one obscurant type meaningful. The transmittance for each obscurant type was printed in standard output for the wavelength band of 0.4 to 0.7 μm; this supplants the printing of transmittance at each of the seven wavelength bands. Also, the aerosol cloud densities at each specified location, instant in time, and obscurant type are printed to a density output file to be used for further analysis or visualization.

The individual density values for each obscurant type were obtained by creating an array variable (CLTOT) that was used in subroutine BTRANS to store the density value for each obscurant type. Within BTRANS, separate subroutines are called in different sections of the code to calculate the densities for puffs and plumes. The densities for these different clouds are then combined within BTRANS for each obscurant type to obtain the total density at each location and time.

The COMBIC code allows the cloud formed to propagate below ground. While this may be useful for selected cases, the modifications were made with the intention of determining densities above ground level. Hence, a value of $Z = 0$ was considered as the minimum Z-value for the observer-to-target LOS. This factor, in combination with the selection of the Z-component of the observer and target locations (on the OLOC and TLOC cards, respectively) indicates the smallest Z-value for which the density is determined. As an example, if the cells were to be represented by cubes 0.5 m on a side, then the Z-value for the observer and target would be 0.5 and 0.0, respectively, and the smallest Z-value for which the density is determined would be at 0.25 m.

3. Code Description and Modifications

To allow COMBIC to provide densities as an output of the model, we had to make several modifications to the code. The file in which the density values are output is specified in standard input. Hence, in addition to the FILE card for the direct access cloud-history file (unit 9), another FILE card is needed for the aerosol cloud-density file (unit 12). This file gives the density values, formatted to one value per line. The header values are output before the densities are written to the file. Included in these header values are the variables that determine the size of the density file, namely, the number of obscurant types, time steps, and cells in the horizontal (X), depth (Y), and vertical (Z) directions. A complete list of the header variables that precede the density data is given in appendix A.

In the earlier version, a two-dimensional printer plot was produced if there was a VIEW card detected in the phase II input. This occurred whether one selected transmission or optical depth. As was originally the case for COMBIC, the VIEW card provides the size of the grid in the X- and Y-directions (variables CLOSW and VLOSW, respectively) and the number of cells (CLOSD and VLOSD) in these respective directions. Now, the input requirements include providing grid information for the vertical direction also, and the previously unused last two positions on the TPOS card are used to input size (ZLOSW) and number of cells (ZLOSD) for this direction. Except for these last two values on the TPOS card, one should set all other values to 0.0. The GREY card is needed for a single variable only, CLOPT, which must be set to 1.0 to ensure that optical depth, not transmittance, is the desired output.

Some cautionary words are necessary regarding the X-, Y-, and Z-values selected for observer and target locations. Since the modifications leading up to this version were made such that densities are calculated for a series of X-Y planes, the LOS is parallel to the Z-axis, a measure of the height above the surface. Hence, the observer and target must have the same value for both the X- and Y-coordinates. For appropriate sign convention, the Z-coordinate of the observer (ZOBS) should be larger than that of the target (ZTAR). In addition, the LOS should be centered within the cell along the Z-direction to ensure that each density is calculated at the center of the cell. Also, since Z is incremented, one must select ZOBS and ZTAR centered on the lowermost cell, i.e., closest to the surface. As an example, if one wants to obtain densities as close to the ground as possible and there are five cells in the Z-direction with the length (size) of 15 m in the Z-direction, then the lowest cell is between 0 and 3 m and centered at 1.5 m. One should select ZOBS = 2.0 and ZTAR = 1.0 to get an LOS path length of 1 m. (The 1-m length corresponds to an assumption that the altered mass extinction coefficient is 1 m^2/g.) The X- and Y-coordinates on the OLOC (and TLOC)

cards represent the center of the X-Y plane of the grid. The densities are calculated at the center of each three-dimensional cell.

The size of the Y-dimension (VLOSW) on the VIEW card is called the vertical extent of viewport. The word vertical was used because it represented the vertical coordinate in the two-dimensional printer plots that were output in the original version of COMBIC. For the three-dimensional case presented in this report, the Y-dimension actually represents the width or depth while the Z-dimension is called the height or vertical position.

The maximum number of allowable sources (INOT) was dimensioned to 50. This is probably a much larger value than is needed and was selected because of the possibility of more than one source having the same obscurant type, which has values from 1 through 30. Because of this possibility, coding was added to SDREAD to eliminate duplicate density-array values for different sources having the same obscurant type. The algorithm initially sets the number of obscurant types (NUMOT) equal to the number of sources and decrements NUMOT each time a duplicate obscurant type is read from input while moving remaining obscurant type values into the next lower array value. The final value calculated for NUMOT represents the number of unique obscurant types that are input for the simulation. INOT and NUMOT were placed in common block CON.

The transmission output printed at the end of the phase II portion of the standard input was modified because we are using only a single wavelength band (0.4 to 0.7 μm). Originally the transmittance at each wavelength band and the optical depth were printed, but now each obscurant type has a different optical depth. Hence, we modified it so that it now prints at each step the transmittance for this band through the observer-to-target LOS and the corresponding optical depths for a maximum of 10 different obscurant types. This number was selected because of the convenience of the data format (i.e., the data for each time step are on a single line of output). If more than 10 obscurant types were used in a simulation, the coding would need to be modified to print the obscurant type values in an appropriate format.

Modifications in BTRANS included determining cumulative values for CLTOT for each obscurant type by making CLTOT an array variable. If a particular source produces both a plume and a puff, the plume portion of the code is executed first. Because of this, the CLTOT value from the plume section of the code was added to the CLTOT calculation in the puff portion to determine the overall density for each time and cell location. CLTOT is then passed to CNTUR, which prints out the density values. Previously, the value of the ODTOT variable in BTRANS was passed to CNTUR and this value was used to plot the transmittance or optical depth. Since only a single wavelength band is printed as output, all loops for the seven wavelength bands were dropped from the coding within BTRANS.

The variable CONC in subroutine CNTUR is used to hold the density values printed to the output file. CONC is a five-dimensional array; these are the number of time steps, the number of different obscurants, and the

number of cells in each of the three orthogonal directions. The array representing the number of obscurants was dimensioned to 30, which is also the number of different obscurant types available in the model. The time step array was dimensioned to 20 because this is currently the maximum number of time steps that can be accommodated by Vis5D. If one desires to visualize the data for more than 20 time steps, the appropriate Vis5D program can easily be modified and recompiled. The number of cells in the three orthogonal directions were each dimensioned to 50.

To help reduce the size of the density file, one must ensure that the first time step for which density values are printed is the first time step where an aerosol cloud for any source appears in the simulation. Density values are then printed until the specified time (the TEND variable on the LIST card) is reached. If all density values are zero for the selected obscurant types, time steps, and cell values, a message is printed to the density file indicating that no aerosol clouds appeared for the time and volume selected. Also, no data are sent to the density file when all values are zero.

For the original version of COMBIC, one needed to indicate the correct value of CLTYP, which is the value of the obscurant type on the EXTC card. This is no longer necessary and would be irrelevant since there would usually be more than one obscurant type value for the multiple obscurant version used to calculate densities. The input value selected for CLTYP, however, will affect the calculated transmittance. The remaining six data values on the EXTC card are the altered mass extinction coefficients for the six different wavelength bands, although only the 0.4- to 0.7-μm band requires the appropriate value, that is, the altered mass extinction coefficient times path length is equal to unity.

4. Results

The individual densities are printed in the following order, from least to most frequently changing variable: obscurant type, time step, horizontal (X), depth (Y), and height (Z). The order of the obscurant types in the density file is the same as the order they appear in phase I of the input. The depth values decrease from largest to smallest while the other three variables increase from smallest to largest value. This order was selected to be consistent with the Vis5D software. The size (bytes) of the aerosol cloud-density file is approximately nine times the product of the number of obscurants, time steps, and cells in the three orthogonal directions.

Figure 1 shows a visualization of the aerosol clouds of five different obscurant types with the use of the Vis5D software. Isosurfaces are shown for the aerosol clouds at 5 s after the starting time for each source. The five different aerosol clouds are the result of sources producing hexachloroethane smoke; fire smoke from a diesel, oil, and rubber mix; a white phosphorus (WP) munition; a red phosphorus munition; and an infrared grenade. The isosurface values for these sources are 10, 10, 10, 10, and 35 percent, respectively, of the maximum values. A degree of opacity is provided to the clouds in the foreground (yellow, green, and blue clouds) to reduce the likelihood that any clouds will be hidden. The volume drawn represents 40 m on a side with each cell being 2 m on a side; hence, there are 20 cells along each orthogonal direction.

The input file used to generate the aerosol clouds in figure 1 is given in appendix B-1. A number of data items in phase II in this file should be pointed out. The third FILE card contains the unit number 12.0 followed by the name of the density file. The fourth data value for the GREY card is 1.0, indicating that the optical depth option was selected. Finally, the last two values on the TPOS card indicate the length of the rectangular grid and the number of cells, respectively, in the Z-direction.

Appendix B-2 gives an abbreviated sample of the output. This abbreviated density file lists the header variables at the beginning of the file and three subheaders that precede the densities for each obscurant type. (The three subheader variables are shown for only the first two obscurant types in this appendix.) The density output file contains several variables required by Vis5D, including the number of obscurant types (line 7), the number of cells in the X-, Y-, and Z-directions (lines 14, 15, and 16, respectively), and the number of time steps (line 17). The Z-values (km), starting on line 19, are also shown in this abbreviated file. The size of this aerosol cloud-density file, which contained 200,000 density values ($20 \times 20 \times 20 \times 5 \times 5$), was approximately 1.8 MB.

The input values used to produce figure 2 are equivalent to those for figure 1 except that the cell size is increased to 4 m on a side. When comparing these two figures, one can see that the larger cell sizes for figure 2 result in a decreased resolution (reduced smoothness) of the clouds. While the isosurface values for figure 2 are the same percentages of the maximum values as those indicated for figure 1, the maximum density values for each respective cloud are different in the two figures.

In figure 3, two different sources (at different locations) that produced hexachloroethane resulted in aerosol clouds that overlapped 3 s after the start time for both sources. A program was written to check on the cloud-density file for this case and to compare it to the sums of the density files for the cases in which each source represented the only input. The results indicate that the values were added together correctly for those cells in which the two aerosol clouds overlapped with the use of this version of the COMBIC model. The input file for this example is shown in appendix B-3.

The multidimensional density grids output with the use of this version of COMBIC are not intended to represent the final product. These density files would then be used by AEROGEN in the WAVES software to represent man-made clouds to influence the WAVES radiative transfer results.

Figure 1. Vis5D visualization of five clouds, each of a different obscurant type.

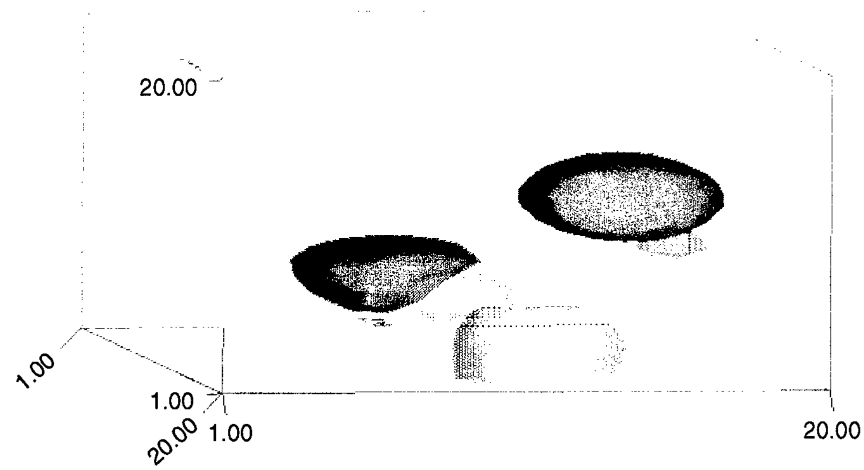


Figure 2. Vis5D visualization of five clouds for case with lower spatial resolution.

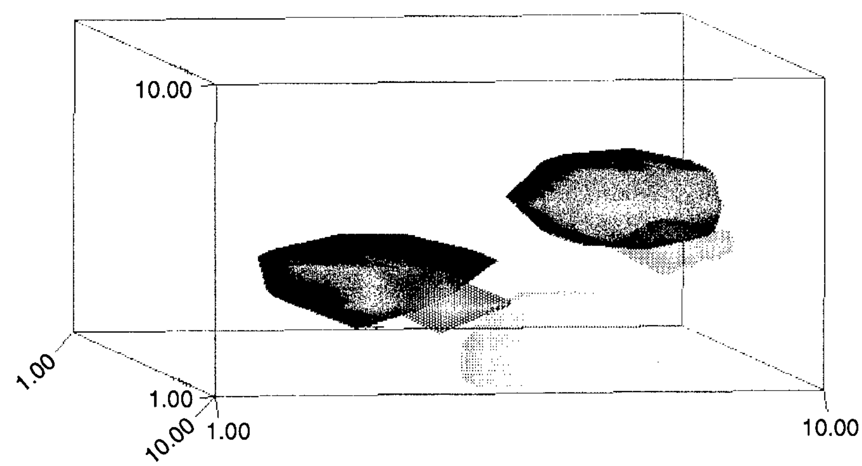
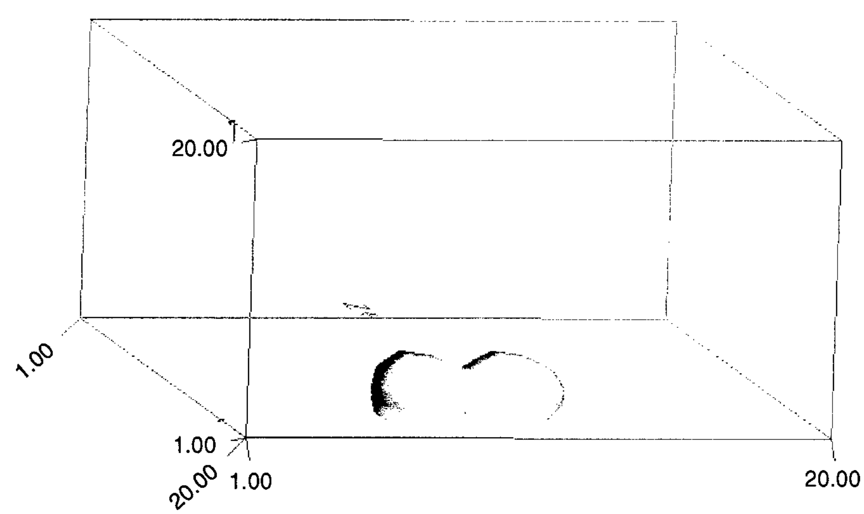


Figure 3. Vis5D visualization of two clouds of same obscurant type.



5. Conclusions

This report provides documentation on the changes made to COMBIC to obtain a density output file for multiple obscurants in the scenario. It also indicates the caveats with which one should be familiar when developing the input for a particular simulation. The aerosol cloud-density output files from this version of COMBIC are expected to be quite useful as input to the AEROGEN software and eventual processing by WAVES. Once it is proven that these files can successfully be incorporated into WAVES, a future COMBIC implementation will optimize the data structures and access routines for obscurant density retrieval rather than use the current path integration method.

References

1. Alan Wetmore and Scarlett D. Ayres, *COMBIC, Combined Obscuration Model for Battlefield Induced Contaminants: Volume 1–Technical Documentation and Users Guide, Volume 2–Appendices*, U.S. Army Research Laboratory, ARL-TR-1831-1 and 2 (2000).

2. Patti Gillespie, Alan Wetmore, and David Ligon, *Weather and Atmospheric Effects for Simulation: Volume 1: WAVES98 Suite Overview*, U.S. Army Research Laboratory, ARL-TR-1721-1 (1998).

3. Vis5D is a system developed by Bill Hibbard, Johan Kellum, and Brian Paul under the University of Wisconsin Space Science and Engineering Center's Visualization Project. The system can be obtained from http://www.ssec.wisc.edu/billh/vis5d.html. The beta release of version 5.2 is available to beta testers at time of writing.

Appendix A. Header Variables

This appendix provides the list of header variables in the aerosol cloud-density file.

Header Variables in Density Output File

Characteristics of the data file

Contents of the data file

Experiment number

Date and time of experiment

Date and time experiment was executed

Number of defined grids (normally set equal to 1)

Number of obscurant types

Reference latitude

Reference longitude

Reference height

Grid identifier (first grid is numbered 0)

Longitude of the southwest corner point

Latitude of the southwest corner point

Number of cells in the X-direction

Number of cells in the Y-direction

Number of cells in the Z-direction

Number of time steps

Number of wavelengths (set equal to 1)

Height (km) of the center of each vertical level of the grid (the number of data values is equal to the number of cells in the Z-direction)

Wavenumbers (cm-1) (the number of wavenumbers is equal to the number of wavelengths)

The following three header values precede each new obscurant type:

Description of data values in file

Obscurant type

Grid identifier number (set equal to 0)

Appendix B. Sample Inputs and Output

This appendix provides the input and abbreviated density-output files for selected cases discussed in the report.

B-1 Input File for Five Sources, Each of a Different Obscurant Type

```
WAVL      1.060000  0.000000  0.000000
COMBIC
PHAS           1.0       3.0       6.0      12.0       9.0       0.0       0.0
FILE           9.0history.out
NAME
Example 3 Sub A and Sub B
MET1          90.0       3.0       2.0      27.5     963.0       0.0       0.0
MUNT      3.000000  0.630000  1.000000  3.000000 92.000000  5.720000  1.000000
GO
MUNT      1.000000  0.790000 30.000000 14.000000 95.000000  7.850000  1.000000
BURN      300.000       0.0       0.0       0.0       0.0    1200.0    0.0008
GO
MUNT      2.000000  0.830000  8.000000  1.000000 82.000000  6.120000  1.000000
GO
MUNT      5.000000  0.850000 21.000000  5.000000 85.000000  6.500000  1.000000
GO
MUNT      7.000000  0.870000 32.000000 20.000000 87.000000  6.700000  1.000000
DONE
END
CONTINUE
WAVL     10.600000  0.000000  0.000000
COMBIC
PHAS           2.0       3.0       6.0      12.0       9.0       0.0       0.0
FILE           9.0history.out
FILE          12.0mulot1.out
NAME
Example 3
ORIG      0.000000  0.000000  0.000000 90.000000270.000000  0.000000
LIST      1.000000  0.000000  5.000000  1.000000
SLOC      1.000000  3.000000  0.000000300.000000 -3.000000-12.000000  3.000000
SLOC      2.000000  1.000000  0.000000300.000000 -7.000000 -6.000000  7.000000
SLOC      3.000000  2.000000  0.000000300.000000-15.000000  0.000000  2.000000
SLOC      4.000000  5.000000  0.000000300.000000  4.000000  6.000000  4.000000
SLOC      5.000000  7.000000  0.000000300.000000 -2.000000 12.000000  8.000000
OLOC           1.0     0.000       0.0       1.5     0.000    70.000
TLOC           1.0     0.000       0.0       0.5       1.0
EXTC           0.0       1.0       1.0       1.0       1.0       1.0       1.0
VIEW           1.0       1.0      40.0      40.0      20.0      20.0      90.0
```

```
GREY        9.0     .01     0.91     1.0     1.0     1.0     0.0
TPOS        0.0     0.0     0.0      0.0     0.0     40.0    20.0
DONE
END
STOP
```

B-2 Abbreviated Density Output File for Five Sources, Each of a Different Obscurant Type

The relevant header variables are discussed in section 4 of the report.

```
densities from COMBIC
COMBIC to AEROGEN
   1
200004211400
200004211500
   1
   5
 -99.000
 -99.000
 -99.000
   0
 -78.000
  39.000
  20
  20
  20
   5
   1
 0.00100
 0.00300
 0.00500
 0.00700
 0.00900
 0.01100
 0.01300
 0.01500
 0.01700
 0.01900
 0.02100
 0.02300
 0.02500
 0.02700
 0.02900
 0.03100
 0.03300
 0.03500
 0.03700
 0.03900
 18100
CLOUD DENSITIES: (g/m**3)
obs   3
   0
  0.0000
  0.0000
  0.0000
   .
```

.
.
0.0000
0.0000
0.0000
0.0000
0.0594
0.1044
0.0971
0.0478
0.0124
0.0000
0.0000
0.0000
.
.
.
0.0000
0.0000
0.0000

CLOUD DENSITIES: (g/m**3)

obs 14
0
0.0000
0.0000
.
.
.
0.0000
0.0000
0.0000

B-3 Input File for Two Sources of the Same Obscurant Type

```
WAVL       1.060000  0.000000  0.000000
COMBIC
PHAS            1.0       3.0       6.0      12.0       9.0       0.0       0.0
FILE            9.0history.out
NAME
Example 3 Sub A and Sub B
MET1           90.0       3.0       2.0      27.5     963.0       0.0       0.0
MUNT       3.000000  0.630000  1.000000  3.000000 92.000000  5.720000  1.000000
DONE
END
CONTINUE
WAVL      10.600000  0.000000  0.000000
COMBIC
PHAS            2.0       3.0       6.0      12.0       9.0       0.0       0.0
FILE            9.0history.out
FILE           12.0mulot4.out
NAME
Example 3
ORIG       0.000000  0.000000  0.000000 90.000000270.000000  0.000000
LIST       1.000000  0.000000  5.000000  1.000000
SLOC       1.000000  3.000000  0.000000300.000000 -3.000000-12.000000  3.000000
SLOC       1.000000  3.000000  0.000000300.000000 -9.000000-12.000000  3.000000
OLOC            1.0     0.000       0.0       1.5     0.000    70.000
TLOC            1.0     0.000       0.0       0.5       1.0
EXTC            3.0       1.0       1.0       1.0       1.0       1.0       1.0
VIEW            1.0       1.0      40.0      40.0      20.0      20.0      90.0
GREY            9.0       .01      0.91       1.0       1.0       1.0       0.0
TPOS            0.0       0.0       0.0       0.0       0.0      40.0      20.0
DONE
END
STOP
```

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U.S. Army Research Laboratory
Attn: AMSRL-CI-EP email: mmungiole@arl.army.mil
2800 Powder Mill Road
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Modifications were made to the Combined Obscuration Model for Battlefield Induced Contaminants (COMBIC) code to obtain aerosol cloud-density values for multiple obscurant types. The main purpose of COMBIC has traditionally been to obtain the transmittance or optical depth for one or more lines of sight (LOSs). If one specifies optical depth, uses consistent units, and ensures that the product of mass extinction coefficient and optical path length is unity, output values will be numerically equal to the cloud density (g/m^3). This report provides information on the required input values, the modifications made to COMBIC, and the resulting output obtained when one or more sources comprising various obscurant types are provided as input. Examples are included that show various cases containing sources with one or more obscurant types as input. The density output files and the resulting visualized clouds are also given in this report. Specific recommendations for the appropriate input values required to produce valid cloud-density grids are indicated.

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